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Non-oxidant thermal treatment for organic waste neutralization

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Abstract

The paper presents the results of experimental approach on organic waste from food industry processing for complete neutralization, energy generation and disposal. Non-oxidant processes pyrolysis based were conducted both at laboratory and pilot scale aiming for product complete neutralization with respect to pathogen germs, bio-degradation and medium-long term storage risk. The results of the study represent alternatives to currently used disposal solutions mainly based on incineration. For the experimental analysis three main waste types were considered: primary stage processing meat industry (feathers), second stage processing meat industry (bones). Noticeable quantities of organic residues such as feather, bone meal, blood and offal waste are generated by poultry processing industries. These residues making up about 25% to 37% of initial product body weight are a considerable waste of the meat processing industry, due to high specific volume, being produced about million tons per year world-wide. Disposal of chicken meat processing industry is a major concern and accumulation of important waste quantities results in environmental pollution of soil, water and air with direct impact on human health. Depending on processing costs the industry sector uses the incineration (usually provided by specialized companies) or the production of meat and bone meal. To limit the risk of disease transmission via feed and food chain the recovery of organic materials for animal feed is banned. The incineration presents the major disadvantage of important energy consumption due high water content of the product together with polluting emissions and low efficiency if energy recovery is used. For the incineration process support fuel is required due to low combustibility properties of the product. With respect to landfiling the products are considered as difficult substrates for anaerobic digestion because of their high protein and lipid content which are inhibitory for the process.

The research focused on the influence of thermal treatment process parameters on product neutralization efficiency and pyrolysis by-products physical-chemical characteristics with respect to energy potential recovery.

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1. Introduction

The poultry processing industry is one of the largest and fastest growing sectors of livestock production in the world [1]. Poultry feathers are a considerable waste product of the poultry industry being produced about 4 million tons per year world-wide [2]. Most of these feathers generated in the industry are currently disposed of by incineration or land filled, which involves expenses and cause environmental problems. Land application of waste from the poultry industry and their negative environmental impact has stimulated interests in the development of alternative disposal methods [3]. Land application of poultry residues can result in runoffs rich in nutrients which can impair water resources. Land application may also result in the spread of pathogens, the production of phytotoxic substances, air pollution and emission of greenhouse gases [4]. Furthermore, excessive land application of poultry residues can result in nitrate (NO_3) contamination of groundwater which can cause methaemoglobinaemia (blue baby syndrome), cancer, and respiratory illness in humans and fetal abortions in livestock [5]. Some poultry residues are hydrolyzed and used as a feed supplement in ruminant, but concerns about bovine spongiform encephalopathy (BSE), commonly known as mad cow disease has resulted the ban on this application [6].

The above environmental implications have stimulated interest in the development of alternative disposal methods to replace the traditional ones. Studies reviewed some methods of poultry industry waste disposal; which include composting (aerobic digestion), anaerobic digestion, and direct combustion. However the major disadvantages of compositing are loss of nitrogen and other nutrients, equipment and labor cost, odor, and availability of land. Slaughterhouses waste are in general considered as difficult substrates for anaerobic digestion because of their high protein and lipid content leading in production of some by-products during anaerobic degradation, which are toxic and inhibitory to anaerobic microorganisms in high concentrations. Chicken feathers are approximately 91% protein (keratin), small amounts of lipids (1%) and water (8%) [7].

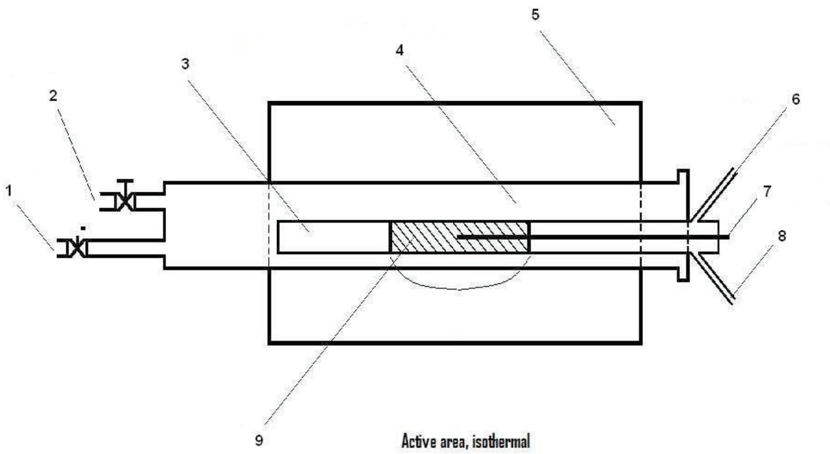
Such practical difficulties have limited and hindered the successful efforts on anaerobic digestion of feathers and other solid poultry slaughterhouse wastes [8]. Direct combustion for heat and power generation is currently being investigated. The United Kingdom has poultry litter combustion plants with capacities ranging from 13.5 MW to 38.5 MW [8].

Unfortunately, this method causes air pollution and would require efficient pollution abatement equipments to meet environmental pollution standards. The low energy efficiency and the fossil fuel support for process run represent current problems of industrial applications. A potential method of solving the poultry residues is to convert it into a useful renewable source of energy or a chemical byproduct with no net increase in carbon dioxide or greenhouse gas equivalents. Fast pyrolysis can be used to convert the product into fuels and chemicals. The thermo-chemical conversion of poultry industry waste to fuels will contribute to the development of the new-bio-based economy as a result of going green, improving the sustainability of rural communities and the health of humans and wildlife. The oil produced from the poultry waste can be used as a substitute for fossil fuels to generate heat, power and/or chemicals.

2. Experimental setup

For the pyrolysis process configuration a tubular electric Nabertherm reactor was used. The reactor was modified according to experiment set-up within Laboratory of Renewable Energy Sources of Polytechnic University of Bucharest. Laboratory scale reactor consists of a refractory stainless steel tube, exterior electrically heated and with an interior diameter of 60 mm. Active heating area has a length of 750 mm. Horizontal tube furnace is equipped with two outlet tubes made for gas and liquid discharges resulted from treatments applied to solid masses. Two inlets are also present (position 1 and 2 on Fig 1.) for treatment gas injection.

Schematic diagram of the main elements of fixed bed furnace is shown in the Fig 1.



1. Nitrogen injection; 2. Air injection; 3. Refractory steel crucible; 4. Refractory steel tube; 5. Electrically heated chamber; 6. Exhaust gases; 7. Thermocouple; 8. Liquid reaction products (tar); 9. Sample

Fig. 1. Tubular batch reactor configuration

Working temperature range is between 20°C and 1300°C. Pyrolysis device is equipped with a control pad that allows temperature programming, working time (residence time at process temperature) and heating rate.

Samples to be subjected to treatment processes are introduced into the furnace in a tubular parallelepiped crucible of refractory steel.

To ensure an inert atmosphere in the oven during the pyrolysis process, nitrogen was continuously fed-in, its flow being measured using a flow controller.

3. Product characterization

Chicken feathers and bones were obtained directly as a waste product from a poultry slaughterhouse in Southern part of Romania. Raw feathers were not clean; blood and other slaughterhouse waste that raised the humidity up to 70% have soaked them. The humidity content of bones is 57%.

After drying in an oven for 24 h at temperature 105ºC the samples were sliced into smaller pieces, powdered in a grinding mill and stored in packed condition at normal room temperature (20–25ºC). The obtained product was used as a starting material for the experimental part.

Elemental composition of the probe was determined experimentally using an Elemental Analyzer EuroEA 3000 series with the working temperature of Gas Chromatography oven 980ºC in the presence of helium and oxygen. The elemental analyzer used is based on Dumas principle of Dynamic Flash

Combustion followed by gas chromatography separation of the resultant gaseous species (N_2, CO_2, H_2O, SO_2) and Thermal Conductivity Detector.

3.1. Proximate analysis

In table 1 are presented the values obtained using calcinations electric heated oven working at a nominal temperature of 800ºC and 1100ºC for the volatile content, fixed carbon and inert of the samples. The volatile content was obtained by heating the sample at 800ºC for 40 minutes under nitrogen atmosphere. The fixed carbon was obtained by burning the pyrolysis char at 1000ºC in air until complete oxidation.

Table 1. Proximate analysis of samples

Sample	Volatiles [%]	Fixed carbon [%]	Inert [%]
Chicken feathers	92	6.5	1.5
Chicken bones	72	22	6

Volatile high values suggest that the ignition of the sample analyzed is very good; that decreases the excess oxygen demand for the burning process.

3.2. Ultimate analysis

In Table 2 are presented the results of the ultimate analysis of samples.

Table 2. Ultimate analysis of the selected fuels

Samples	C [%]	H [%]	N [%]	S [%]	O [%]	Cl [%]	Inert [%]
Chicken Feathers	60.6	8.5	8.7	4.8	13.3	2.6	1.5
Chicken Bones	47.2	6.9	6.1	3.3	28.0	2.2	6.3

The values of the combustible fraction of samples indicate that the calorific value that will be calculated is very good. The content of pollution sources form of chlorine is low resulting in a combustion gas discharge with low emissions of Cl. The presence of sulphur (about 5% for feathers) is due to blood and organ presence, but the current SO_2 retention installations can be used.

4. Pyrolysis treatment. Results and discussions.

The pyrolysis process was conducted at temperatures in range 400ºC – 800ºC under nitrogen atmosphere for each product separately. Here below we present the sample mass variation during thermal degradation of dry chicken feathers and bones.

The results highlight the influence of temperature and residence time on thermal degradation. For low temperature pyrolysis the 40 minutes treatment period is not sufficient for complete volatile fraction liberation. At this temperature the carbon from solid matrix of the sample can not break the links and combine with H and O for gas phase conversion.

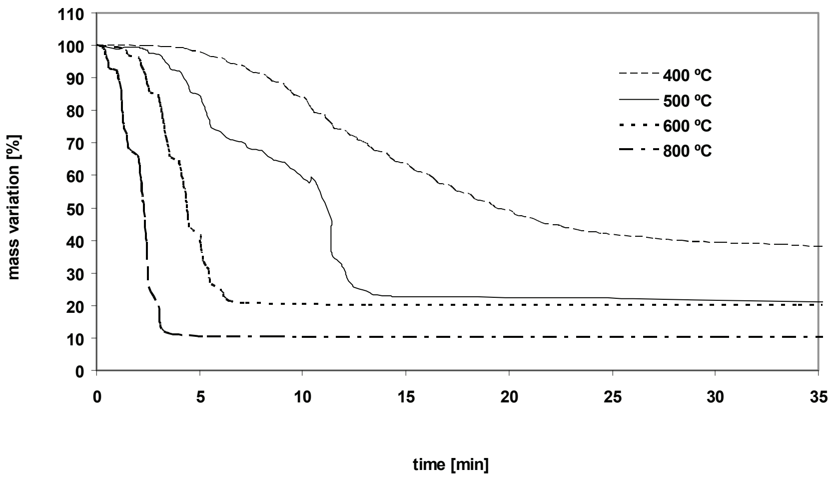


Fig. 2. Chicken feathers mass variation under pyrolysis conditions (nitrogen atmosphere).

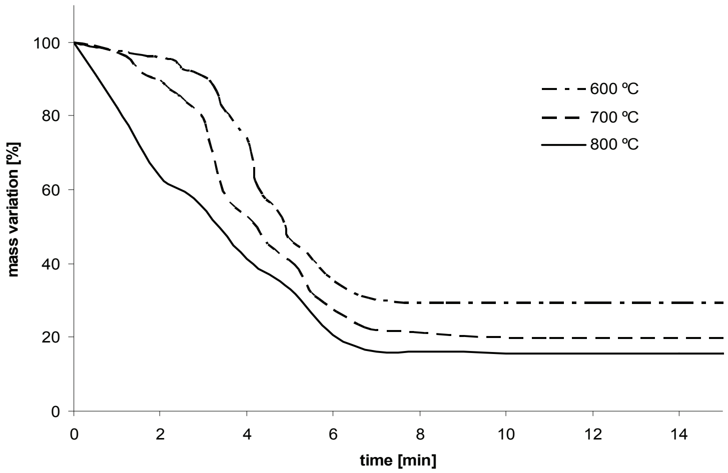


Fig. 3. Chicken bones mass variation under pyrolysis conditions (nitrogen atmosphere)

At 500ºC the pyrolysis processes is initiated after 4 minutes and continues for about 11 minutes till complete char formation. The pyrolysis at 600ºC is similar to 500ºC with respect to volatile fraction liberation, even if the process starts in 2 minutes approximately. The high temperature pyrolysis increases the breaking of C-C links with direct effect on char fraction that decreases from 20% to approximately 11%. As we expected liberated gases: H_2, CO and CH_4 increase their content at higher temperature having a faster variation within the first 2 minutes, but the CO_2 quantity is quasi constant depending only on the O_2 concentration as we operate under auto-pyrolysis conditions (due to O_2 presence in raw product). Similar mass variation was recorded for the bones samples, the 550ºC - 600ºC being the recommended treatment temperature for complete char formation in less than 1 hour. Bellow this temperature, and depending on product size, some zones may remain un-carbonized. As the presence of bones in raw product is reduced the overall pyrolysis process kinetics is dictated by the feathers and blood and other slaughterhouse waste.

The pyrolysis by-products consisting in char, tar and pyrolysis gas were investigated in order to establish their composition and LHV together with sulphur and chlorine migration within these products as function of treatment temperature.

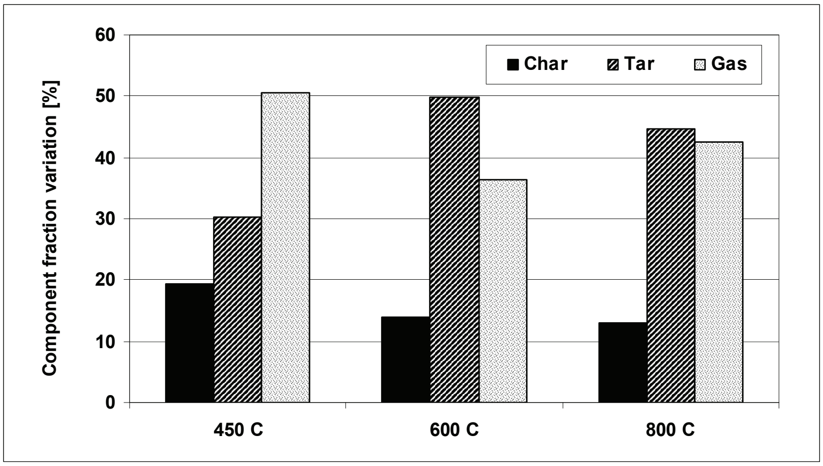


Fig. 4. Pyrolysis by-products fraction depending on treatment temperature.

In Fig 4 the repartition of char, tar and pyrolysis gas in process by-products is presented. We notice the decrease of char fraction and increase tar content. At 600ºC the tar content is maxim due to massive carbon presence. Above this temperature the second chain of reaction in gaseous phase is initiated and tar content decreases with pyrolysis gas (non-condensing) increase. The elemental analysis of char and tar revealed the presence of sulphur in tar composition (table 3). Its concentration increases with temperature rise. The high heating value of each product was determined directly by calorimetric experiment and the low heating value (LHV) was calculated based on hydrogen content. The results revealed an important energy potential of pyrolysis by-products provided by the LHV superior to 23000 kJ/kg. For this specific energy content any thermal conversion chain can be applied: combustion or gasification. Based on pyrolysis gas analysis the LHV was calculated between 6000 – 7300 kJ/Nm^3.

Table 3. Elemental analysis of solid and liquid pyrolysis by-products

450ºC	C [%]	H [%]	N [%]	S [%]	O [%]	Cl [%]	Inert [%]	LHV [kJ/kg]
Char	67.2	4.7	10.1	0.5	5.9	5.7	5.9	26638
Tar	52.1	9.1	6.5	4.1	25.1	3.1	0	23251
600ºC	C [%]	H [%]	N [%]	S [%]	O [%]	Cl [%]	Inert [%]	LHV [kJ/kg]
Tar	59.3	9.4	8.1	4.6	17.1	1.5	0	27837
800ºC	C [%]	H [%]	N [%]	S [%]	O [%]	Cl [%]	Inert [%]	LHV [kJ/kg]
Tar	62.2	10.2	7.1	4.8	9.3	6.4	0	27601

The tar LHV increases with process temperature due to carbon conversion from solid to condensable hydrocarbons. Chlorine is present in tar at low temperatures and migrates to liquid and gaseous phase at medium temperature.

5. Conclusions

The energy recovery via thermal-chemical processes is promising waste management solution for poultry feathers and bones derived like waste. Depending on site specific conditions a pre-treatment pyrolysis stage can be applied for raw product stabilization, neutralization and combustibility properties improvement. In its raw form the product neutralization using incineration requires important additional support fuel and the technique not so environmental friendly when applied to heterogeneous waste with Cl content due to dioxins potential emissions. The high-energy potential of this type of product when completely dried, almost 27 MJ/kg_{dried_base} compared to wood 13 - 17 MJ/kg recommends the thermal processing. The pyrolysis pre-treatment process could represent a solution for product homogenization and water removal. Conducted at low and medium temperature (450ºC - 600ºC) the pyrolysis process can generate superior energy potential by–products: gas, tar and char. The LHV of solid and liquid by-products is considerably high 23 – 28 MJ/kg. The pyrolysis gas (about 6500 kJ/Nm^3) can be used for process energy support. If local electric energy demand is present the char and tar steam-gasification followed by Otto-Diesel or Brayton cycle could be a viable solution. The important water content of the raw product could cover the water/carbon ratio required by gasification stage. Conducted at 850ºC – 1100ºC the steam gasification can neutralize 99.9% of waste reaching incineration performance.

Acknowledgement

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References

[1] Sims JT, Wolf DC. Poultry waste management: agricultural and environmental issues. *Adv. Agronomy* 1994; **52**: 1-83.

[2] Salminen E, Rintala J. Semi-continuous anaerobic digestion of solid poultry slaughterhouse waste: effect of hydraulic retention time and loading. *Water Research* 2002; **36**: 3175–82.

[3] Abelha P, Gulyurtlu I, Boavida D, Seabra Barros J, Cabrita I, Leahy J, Kelleher B, Leahy M. Combustion of poultry litter in a fluidized bed combustor. *Fuel* 2003; **82**: 687-92.

[4] Kelleher BP, Leahy JJ, Henihan AM, O'Dwyer TF, Sutton D, Leahy MJ. Advances in poultry litter disposal technology- a review. *Bioresource technology* 2002; **83**: 27- 36.

[5] Bitzer CC, Sims JT. Estimating the Availability of Nitrogen in Poultry Manure through Laboratory and Field Studies. *J Environ Qual* 1988; **17**: 47-54.

[6] Herson M, Dubberly D, Kelly F. *Poultry Litter Feeding Ban: Implications of the 2nd Interim Rule for Animal Feeding*, Florida Cooperative Extension service; 2004.

[7] Jeffrey WK. *Physical and mechanical properties of chicken feather materials. Master Thesis*, Georgia Institute of Technology; 2006.

[8] Salminen E, Einola J, Rintala J. The methane production of poultry slaughtering residues and effect of pretreatments on the methane productivity of poultry feather. *Environmental Technology* 2003; **24**: 1079-86.